

CO₂ Sequestration in Appalachian Coal Seams Using Pinnate Well Patterns

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Summary

Injection of carbon dioxide into unminable coal seams is a promising technology for long-term CO₂ sequestration which has the extra advantage of enhancing the coalbed methane recovery. Feasibility of CO₂ sequestration in depleted oil and gas reservoirs is currently being investigated as pilot projects in North America and some European countries.

Among different well patterns currently used for primary recovery of coalbed methane, horizontal pinnate wells show promise. They demonstrate high methane recovery in a short period of time along with cost reductions and smaller footprints. Can these same characteristics make them better candidate for CO₂ sequestration?

In this study, a pinnate well is first used for production and then for CO₂ injection to enhance the methane recovery and eventually long term sequestration. The large contact area between the wellbore and the formation helps fast dewatering, hence producing the methane, which is desorbed from the coal matrix into the natural fractures. The pinnate pattern distributes the CO₂ in a large area of the formation before it reaches the producing wells. Therefore, a larger amount of CO₂ could be stored in the formation before CO₂ breakthrough occurs.

In this paper, a feasibility study of CO₂ sequestration using pinnate patterns into a coal seam in the Appalachian Basin is presented. Several characteristics of the pinnate pattern and the CO₂ injection strategies are studied and optimized using a numerical reservoir simulator in order to increase the methane recovery and total CO₂ that can be stored before breakthrough.

Methodology

Sensitivity analysis was performed on a few reservoir and well parameters using a numerical reservoir simulator in order to study their effect on CO₂ storage. In this analysis, an optimum value for injection rate and space between laterals for the pinnate pattern was identified. The parameters studied here and their ranges are:

- Space between laterals, 250, 500, 750, 1000, 1250, and 1500 ft
- Injection Rate, from 100 to 1000 MSCF/D
- Gas Content (CO₂/CH₄ ratio), 2, 4, 6, and 8
- Permeability, 5, 10, and 100 mD
- Desorption time, 5, 50, 100, and 300 days

The field under study had a parallelogram shape with the pinnate well inside and two dual-lateral horizontal wells on two opposite corners, which their laterals were on the borders of the field. These two horizontal wells were producers in the whole period of the simulation. In this study, all the calculations of total CO₂ storage were at the time of CO₂ breakthrough, which is when CO₂ production at the producers was 10% of the total gas production.

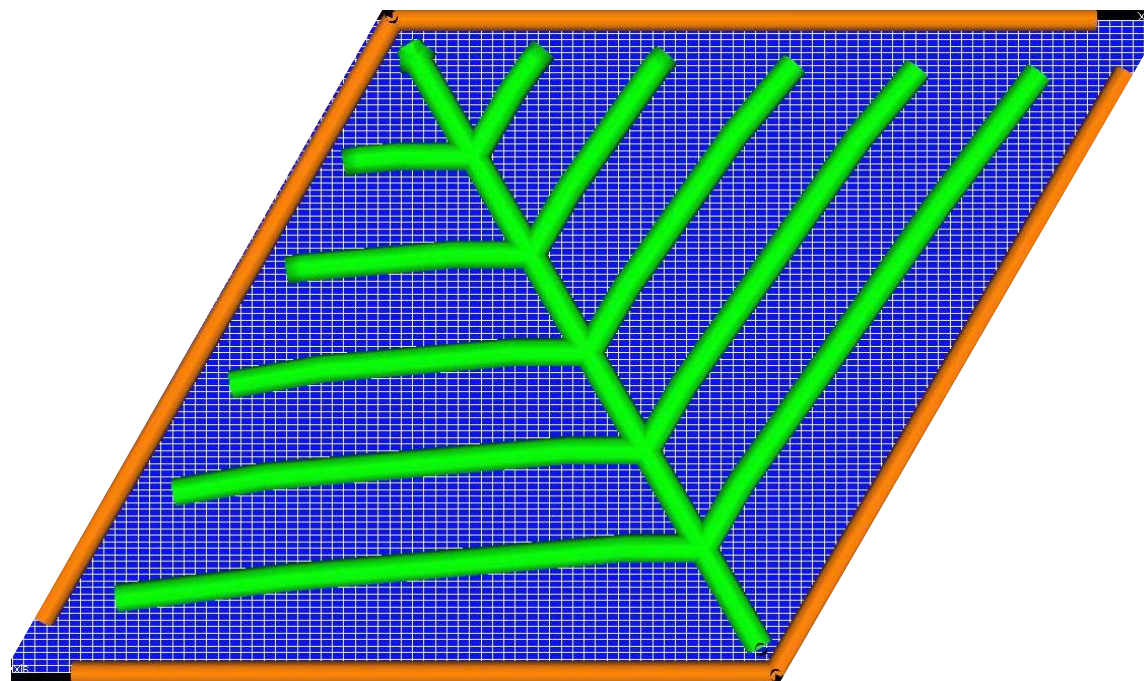
Well Pattern and Reservoir Shape

Figure 1 shows the pinnate pattern. There are two dual-lateral horizontal wells (in brown) on the opposite corners of the parallelogram

Table 1 shows the fluid and reservoir properties for the base model.

Property	Value
Depth, ft	1400
Thickness, ft	5
Area, acres	497
Fracture porosity, %	5
Permeability in X and Y direction, mD	20
Permeability in Z direction, mD	2
Initial reservoir pressure, psia	800
Bottom-hole pressure, psia	50
Reservoir temperature, °F	75
Gas gravity	0.7
Gas desorption time, days	50
CH ₄ Langmuir pressure constant, psia	680
CH ₄ Langmuir volume constant, Mscf/ft ³	0.0215

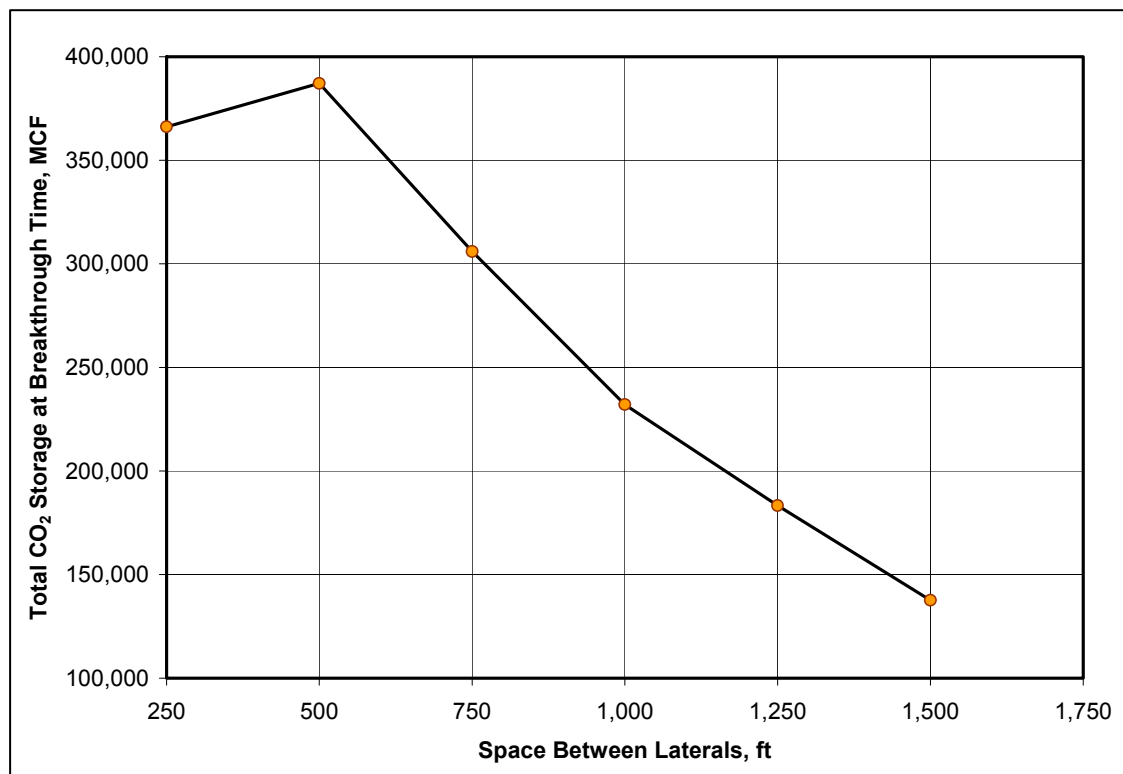
Sensitivity Analysis on Space between Laterals

Figure 2 shows the total volume of stored CO₂ for different space between laterals.

The optimum value for space between laterals for this model was found to be around 500 feet. This value will give the optimum number of laterals on each side of the main leg and will cover all the area in the reservoir.

Sensitivity Analysis on CO₂ Injection Rate

Injection rate was optimized for this model by changing its value and finding the maximum amount of CO₂ storage for each model. The optimum injection rate for this model was found to be between 500 and 600 MCF/D.

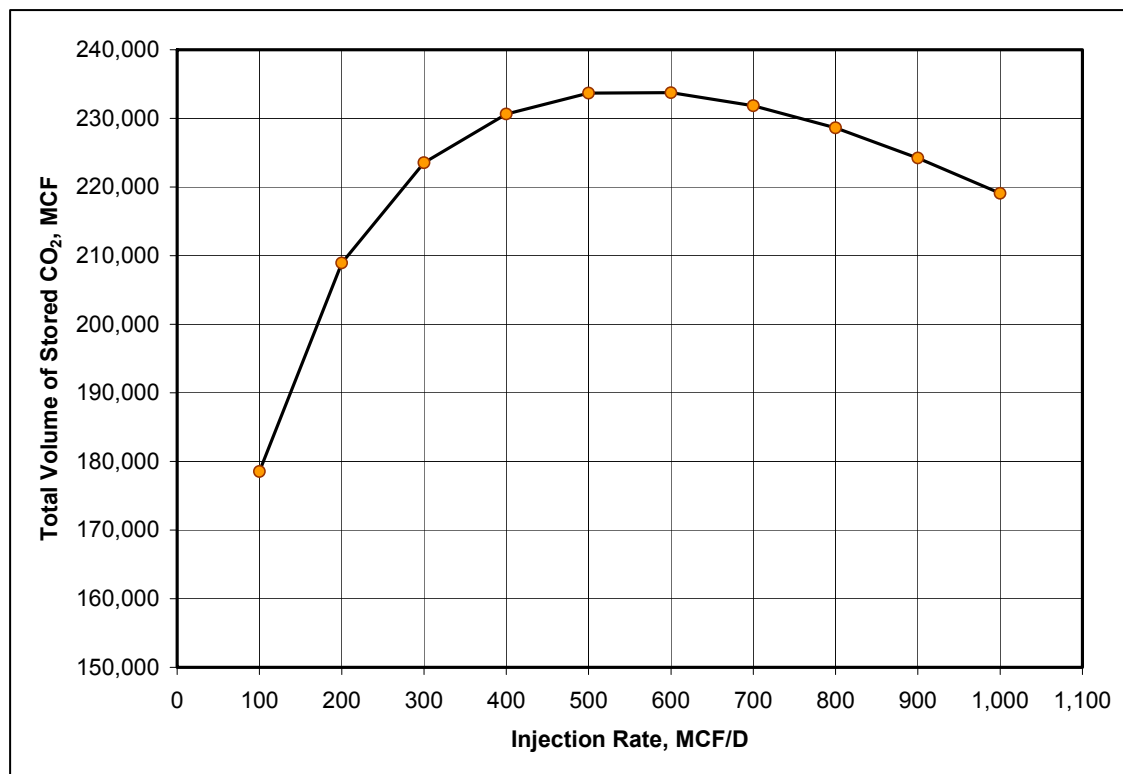


Figure 3 shows the total volume of stored CO₂ for different injection rates.

Sensitivity Analysis on CO₂/CH₄ Ratio

CO₂/CH₄ ratios selected were 2, 4, 6, and 8 keeping the CH₄ isotherm to be constant. The results show that the higher the ratio is, the higher the total volume of CO₂ storage will be. If CH₄ isotherm is also changed, then the original gas in place should be noticed. In any case, the percentage of CO₂ storage over the original methane in place will increase by increasing this ratio.

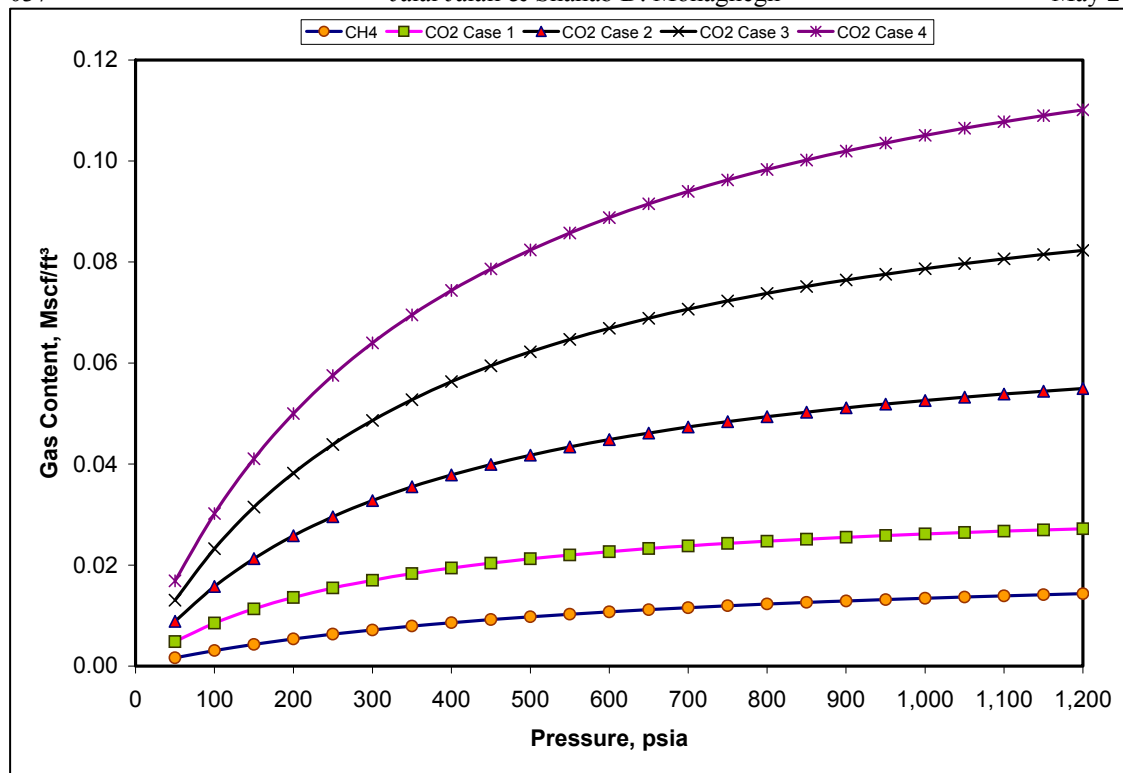


Figure 4 shows the isotherms for CO₂ and CH₄.

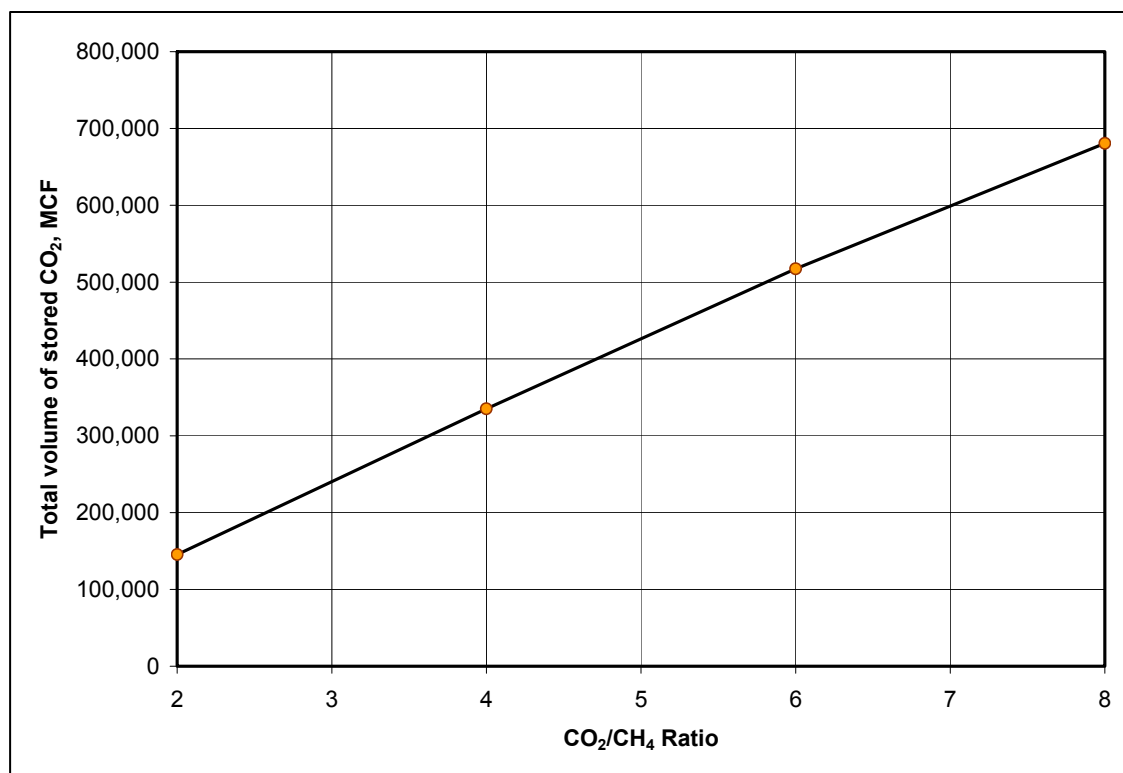


Figure 5 shows the total volume of stored CO₂ for different CO₂/CH₄ ratios.

Sensitivity Analysis on Fracture Permeability

The values of the permeability for different directions were chosen to be 5, 10, and 100 mD for X and Y directions. The value of the permeability in Z-direction was selected to be one-tenth of the value of X-direction. The results of the simulations show that the total volume of stored CO₂ will decrease with increasing the fracture permeability. This is because of decrease in CO₂ injection period due to fast CO₂ breakthrough.

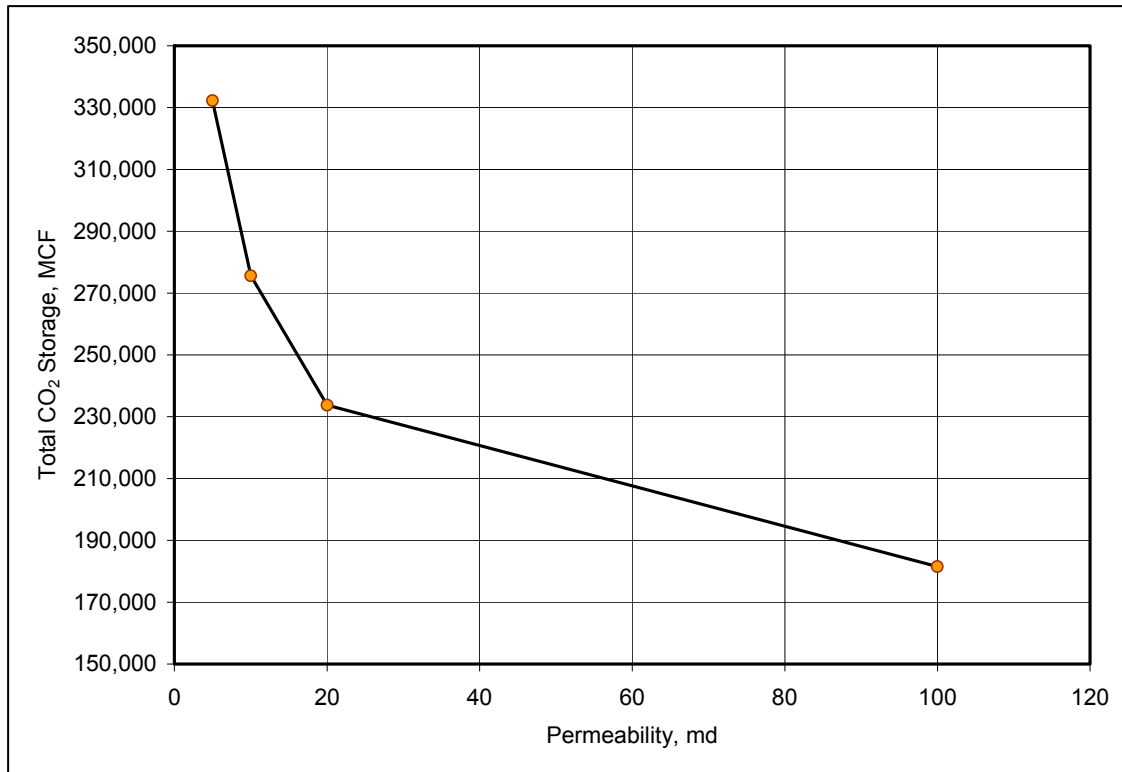


Figure 6 shows the total volume of CO₂ stored in the formation for different fracture permeability values.

Sensitivity Analysis on Desorption Time

As it is shown on figure 7, total volume of stored CO₂ will decrease by increasing the desorption time.

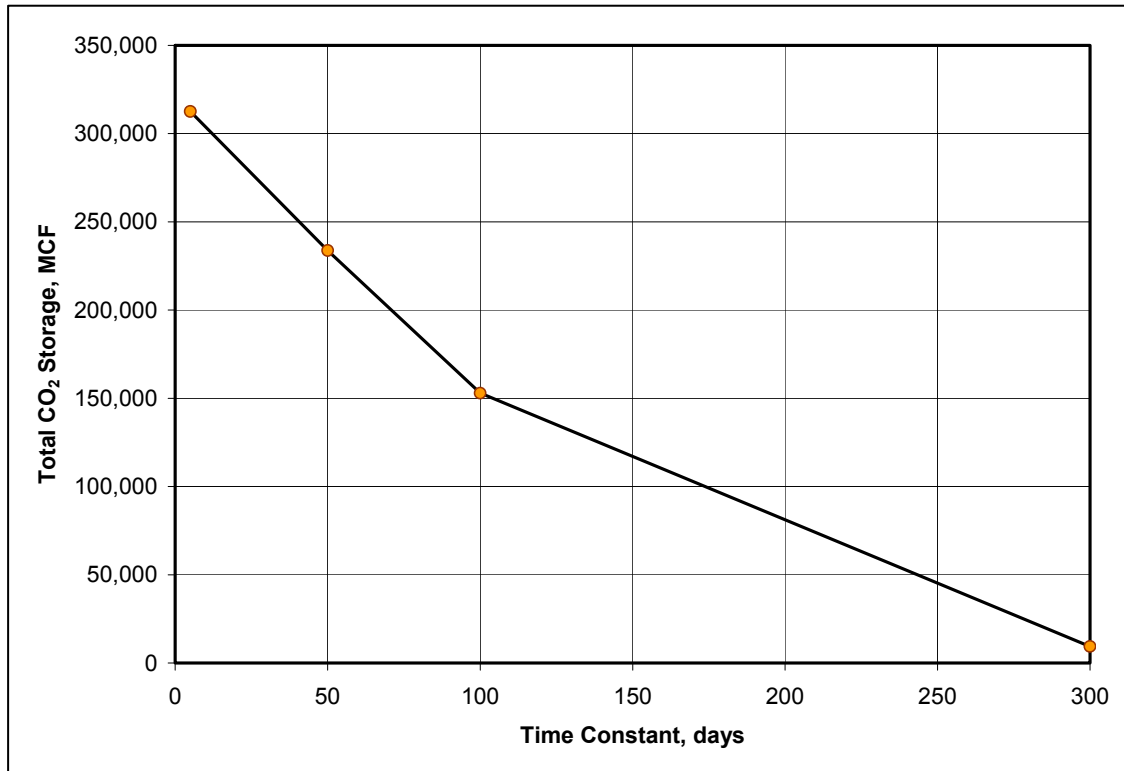


Figure 7 shows the total volume of CO₂ stored in the formation for different desorption times.

Conclusion

- Higher permeability values result in less CO₂ storage.
- High desorption time will result in less CO₂ storage.
- Higher CO₂/CH₄ ratio will provide higher CO₂ storage.
- Considering the reservoir and fluid properties in this model, the optimum space between laterals was found to be around 500 ft for obtaining maximum CO₂ storage.
- Also the optimum value of CO₂ injection rate was found to be between 500 and 600 MCF/D in order to obtain maximum CO₂ storage before the breakthrough occurs.